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INTRODUCTION

The land application of wastewater or treated effluent entails the use of plants, the soil surface, and the soil matrix for removal of certain wastewater constituents. In addition to treatment, land application systems may be used for a combination of water reuse and disposal, with the renovated water either discharged to the groundwater or collected for discharge to surface waters.

For most land application systems, a wide range of design possibilities is available to suit specific site characteristics, climate, treatment requirements, and project objectives. The scope of factors that are normally considered in the design process is shown in table 1. It should be noted that the list is representative and not necessarily all-inclusive.

Table 1.—*General design considerations*[1]

Wastewater characteristics	Climate	Geology	Soils	Plant cover	Topography	Application
Flow volume	Precipitation	Groundwater	Type	Indigenous to region	Slope	Method
Constituent load	Evapotranspiration	Seasonal depth	Gradation	Nutrient removal capability	Aspect of slope	Type of equipment
	Temperature	Quality	Infiltration/ permeability	Toxicity levels	Erosion hazard	Application rate
	Growing season	Points of discharge	Type and quantity of clay	Moisture and shade tolerance	Crop and farm management	Types of drainage
	Occurrence and depth of frozen ground	Bedrock	Cation exchange capacity	Marketability		
	Storage requirements	Type	Phosphorus adsorption potential			
	Wind velocity and direction	Depth	Heavy metal adsorption potential			
		Permeability	pH			
			Organic matter			

Because land application by nature must be site specific, and because a wide range of design possibilities is available, it is not well-suited to standardized design guidelines. The few guidelines that have been written are generally limited in scope, dealing mainly with spray irrigation. In lieu of guidelines, the designer must rely on a comprehensive understanding of the principles involved, site evaluation by specialists, and his own ingenuity. A multi-disciplinary approach to planning land application systems is necessary, encompassing fields such as

- Environmental engineering
- Hydrology
- Soil science
- Agriculture
- Geology
- Land use planning

Chapter I

OBJECTIVES OF LAND APPLICATION METHODS

The three basic methods of land application are irrigation, infiltration-percolation, and overland flow. Each method, shown schematically in figure I-1, can produce renovated water of different quality, can be adapted to different site conditions, and can satisfy different overall objectives.

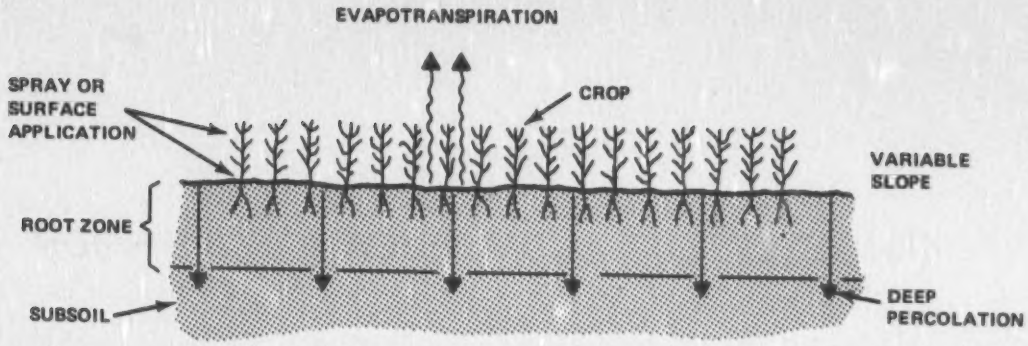
IRRIGATION

Irrigation, the predominant land application method in use today, involves the application of effluent to the land for treatment and for meeting the growth needs of plants. The applied effluent is treated by physical, chemical, and biological means as it seeps into the soil. Effluent can be applied to crops or vegetation (including forestland) either by sprinkling or by surface techniques, for purposes such as:

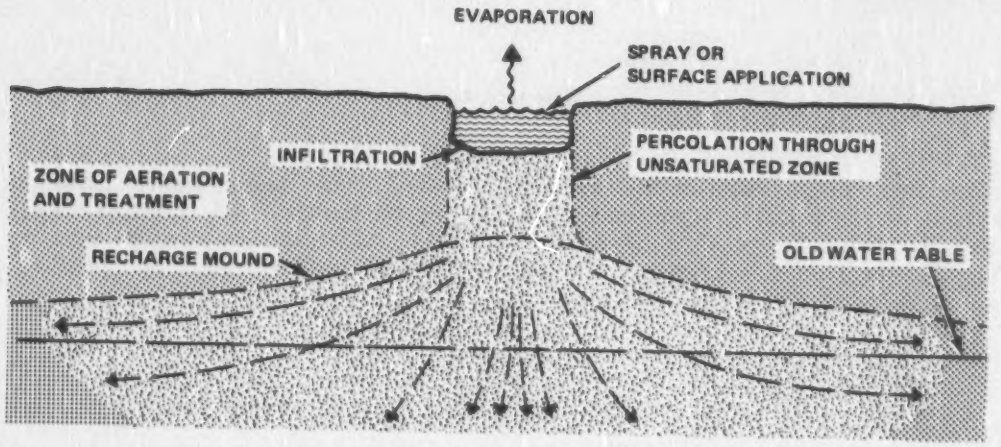
- Avoidance of surface discharge of nutrients
- Economic return from use of water and nutrients to produce marketable crops
- Water conservation by exchange when lawns, parks, or golf courses are irrigated
- Preservation and enlargement of greenbelts and open space

Where water for irrigation is valuable, crops can be irrigated at consumptive use rates (1 to 3 in./wk, depending on the crop), and the economic return from the sale of the crop can be balanced against the increased cost of the land and distribution system. On the other hand, where water for irrigation is of little value, hydraulic loadings can be maximized (provided that renovated water quality criteria are met), thereby minimizing system costs. Crops grown under high-rate irrigation (2.5 to 4 in./wk) are usually water-tolerant grasses with lower potential for economic return but with high nutrient uptakes.

When requirements for surface discharge are very stringent with regard to nitrogen, phosphorus, and BOD, irrigation can meet the objectives by avoiding a surface discharge, provided that groundwater criteria can be met. If the renovated water quality must meet Environmental Protection Agency drinking water standards, reduction in nitrogen below the 10 mg/l standard for nitrate nitrogen is often the limiting criterion. In arid regions, however, increases in chlorides and total dissolved salts in the groundwater may be limiting.



(A) IRRIGATION



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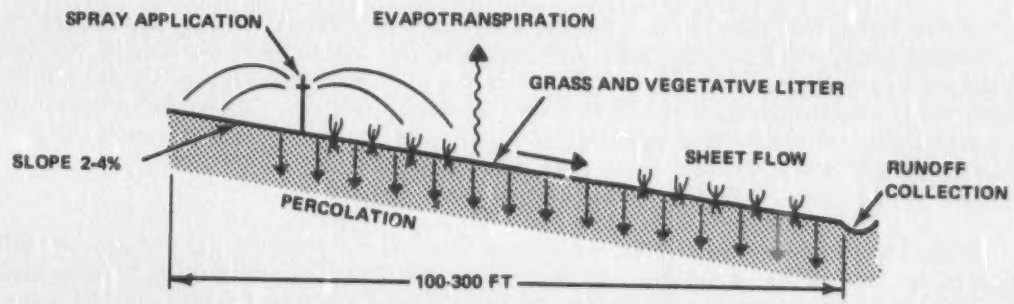

(C) OVERLAND FLOW

Figure I-1. Methods of land application.

INFILTRATION-PERCOLATION

In infiltration-percolation systems, effluent is applied to the soil at higher rates by spreading in basins or by sprinkling. Treatment occurs as the water passes through the soil matrix. System objectives can include:

- Groundwater recharge
- Natural treatment followed by pumped withdrawal or underdrains for recovery
- Natural treatment with renovated water moving vertically and laterally in the soil and recharging a surface watercourse

Where groundwater quality is being degraded by salinity intrusion, groundwater recharge can reverse the hydraulic gradient and protect the existing groundwater. Where existing groundwater quality is not compatible with expected renovated quality, or where existing water rights control the discharge location, a return of renovated water to surface water can be designed, using pumped withdrawal, underdrains, or natural drainage. At Phoenix, Arizona, for example, the native groundwater quality is poor, and the renovated water is to be withdrawn by pumping, with discharge into an irrigation canal.

OVERLAND FLOW

Overland flow is essentially a biological treatment process in which wastewater is applied over the upper reaches of sloped terraces and allowed to flow across the vegetated surface to runoff collection ditches. Renovation is accomplished by physical, chemical, and biological means as the wastewater flows in a thin sheet down the relatively impervious slope.

Overland flow can be used as a secondary treatment process where discharge of a nitrified effluent low in BOD is acceptable or as an advanced wastewater treatment process. The latter objective will allow higher rates of application (5 in./wk or more), depending on the degree of advanced wastewater treatment required. Where a surface discharge is prohibited, runoff can be recycled or applied to the land in irrigation or infiltration-percolation systems.

Chapter II

PREAPPLICATION TREATMENT

Treatment of wastewater prior to land application may be necessary for a variety of reasons, including:

- Maintaining a reliable distribution system
- Allowing storage of wastewater without nuisance conditions
- Maintaining high infiltration rates into the soil
- Allowing irrigation of crops that will be used for human consumption

In the following paragraphs, minimum preapplication treatment levels are described for irrigation, infiltration-percolation, and overland flow, and wastewater quality is briefly discussed.

IRRIGATION

Irrigation has been conducted successfully with food processing wastewater containing BOD and suspended solids concentrations several times higher than those in municipal wastewaters.[2] Preapplication treatment for these industrial wastewaters often involves only screening to keep the distribution system from clogging. Consequently, reduction of BOD and suspended solids in municipal wastewaters is not generally necessary from the standpoint of loadings on the soil. Reductions may be necessary, however, where clogging of the distribution system may occur, where disinfection is required, or where considerable storage is required.

The bacteriological quality of municipal wastewater is usually limiting where food crops or landscape areas (parks, golf courses, etc.) are to be irrigated or where aerosol generation by sprinkling is anticipated (see Chapter VIII, *Public Health Considerations*). Pathogens should be reduced to a level consistent with the protection of public health.

Generally, the state public health agencies place limitations on the quality of municipal wastewater that can be used for irrigation. In California, for example, biological treatment plus disinfection to a total of 23 coliform organisms per 100 milliliters is required for irrigation of golf courses, parks, freeway landscapes, and pastures grazed by milking animals. For direct irrigation of food crops, California requires oxidized, coagulated, filtered wastewater disinfected to a total of 2.2 coliform organisms per 100 milliliters. Primary effluent is acceptable for surface irrigation of orchards, vineyards, and fodder, fiber, and seed crops in California.

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For many other states having guidelines, effluent of the quality produced by lagoons is acceptable for irrigation. In Virginia, for example, lagoon effluent can be used to irrigate all crops except those to be consumed raw (which cannot be irrigated with any effluent).

In Missouri, irrigation of forage crops and golf courses is permitted with effluent disinfected to 200 fecal coliforms per 100 milliliters. Secondary treatment is required only to provide effective disinfection.

INFILTRATION-PERCOLATION

Reduction of suspended solids is the most important preapplication treatment criterion for infiltration-percolation systems, so that soil clogging and nuisance conditions from odors are minimized. Biological treatment is often provided for this purpose. Disinfection is generally not necessary, except possibly for sprinkling systems, as a number of studies have shown infiltration-percolation to be quite effective in the reduction of pathogenic bacteria.[2]

OVERLAND FLOW

When overland flow is used as a secondary treatment process, the minimum preapplication treatment is screening and possibly grit and grease removal to avoid clogging the distribution system. No food crops are grown, and sprinkling systems can be designed to minimize the generation of mists by using rotating-boom sprays or by sprinkling at low pressures. In the pilot system at Ada, Oklahoma, raw comminuted wastewater, which was settled for 10 minutes for grease and grit removal, was applied successfully using 30-foot diameter rotating-boom sprays discharging slightly downward at 15 psi.[3]

When used as an advanced wastewater treatment process, lagoon or conventional secondary effluent can be used. Nitrification prior to land application is not necessary for nitrogen removal by denitrification; however, nitrified effluent can be treated successfully for nitrogen removal. Disinfection prior to application may avoid post-disinfection and allow sprinkling at higher pressures.

WASTEWATER QUALITY

The composition of most municipal wastewater effluent is acceptable for land application. The effluent quality of 12 selected secondary treatment plants discharging to the land is summarized in table II-1. Nitrogen, the constituent that will most often limit the liquid loading rate, is discussed in Design Factors – II.

Suggested values for major inorganic constituents in water applied to the land are shown in table II-2. In arid portions of the country, total dissolved solids may present a hazard in irrigating certain crops. Crops vary in their tolerance to salinity and boron.[8,9]

Table II-1.—*Quality of selected secondary effluents applied to the land*

Constituent	Values, mg/l (except as noted)	
	Range	Average
BOD	6-42	26
Suspended solids	12-88	48
TDS[a]	480-1,235	900
Total nitrogen	6.5-33.4	18.5
Total phosphorus	2.1-16.0	8.8
Sodium	40-260	160
SAR[b]	1.3-7.4	4.1
Boron	0.4-1.0	0.7

[a]TDS = total dissolved solids.
[b]SAR = sodium adsorption ratio.
Sources: Data for Abilene, Tex.; Conejo Valley Sanitary District, Calif.; Oak View Sanitary District, Calif.; Pomona, Calif.[4]
Data for Moulton-Niguel Water District, Calif.; Phoenix, Ariz.; Lake George, N.Y.; Westby, Wis.; Woodland, Calif.[2]
Data for Muskegon, Mich.[5]
Data for Michigan State, Mich.[6]
Data for Pennsylvania State, Pa.[7]

Sodium can be toxic to crops; however, it usually affects permeability first. The sodium adsorption ratio should be maintained below 9 to prevent deflocculation of the soil structure or sealing of the soil.[2] The sodium adsorption ratio is of special concern when the soil has a high clay content. It can be reduced by increasing the wastewater concentrations of calcium and magnesium through the addition of gypsum or other amendments.[8] The effects of other wastewater constituents, such as heavy metals, are addressed in Design Factors – II.

Table II-2.—*Suggested values for major inorganic constituents in water applied to the land*[10]

Problem and related constituent	No problem	Increasing problems	Severe
Salinity[a]			
EC of irrigation water, in millimhos/cm	<0.75	0.75-3.0	>3.0
Permeability			
EC of irrigation water, in mmho/cm	>0.5	<0.5	<0.2
SAR (Sodium adsorption ratio)[b]	<6.0	6.0-9.0	>9.0
Specific ion toxicity[c]			
From root absorption			
Sodium (evaluate by SAR)	<3	3.0-9.0	>9.0
Chloride, me/l	<4	4.0-10	>10
Chloride, mg/l	<142	142-355	>355
Boron, mg/l	<0.5	0.5-2.0	2.0-10.0
From foliar absorption[d] (sprinklers)			
Sodium, me/l	<3.0	>3.0	–
Sodium, mg/l	<69	>69	–
Chloride, me/l	<3.0	>3.0	–
Chloride, mg/l	<106	>106	–
Miscellaneous[e]			
NH_4-N, NO_3-N mg/l for sensitive crops	<5	5-30	>30
HCO_3, me/l [only with overhead sprinklers]	<1.5	1.5-8.5	>8.5
HCO_3, mg/l [only with overhead sprinklers]	<90	90-520	>520
pH	Normal range = 6.5-8.4		

[a]Assumes water for crop plus needed water for leaching requirement (LR) will be applied. Crops vary in tolerance to salinity. Electrical conductivity (EC) mmho/cm x 640 = approximate total dissolved solids (TDS) in mg/l or ppm; mmho x 1,000 = micromhos.

[b]$SAR = \frac{Na}{\sqrt{\frac{Ca + Mg}{2}}}$ where Na = sodium, milliequivalents/l; Ca = calcium; Mg = magnesium.

[c]Most tree crops and woody ornamentals are sensitive to sodium and chloride (use values shown). Most annual crops are not sensitive.

[d]Leaf areas wet by sprinklers (rotating heads) may show a leaf burn due to sodium or chloride absorption under low-humidity, high-evaporation conditions. (Evaporation increases ion concentration in water films on leaves between rotations of sprinkler heads.)

[e]Excess N may affect production or quality of certain crops, e.g., sugar beets, citrus, grapes, avocados, apricots, etc. (1 mg/l NO_3-N = 2.72 lb N/acre-ft of applied water.) HCO_3 with overhead sprinkler irrigation may cause a white carbonate deposit to form on fruit and leaves.

Note: Interpretations are based on possible effects of constituents on crops and/or soils. Suggested values are flexible and should be modified when warranted by local experience or special conditions of crop, soil, and method of irrigation.

Chapter III

LAND SUITABILITY

A checklist of characteristics to be evaluated for land suitability, included in *Evaluation of Land Application Systems*,[9] contains the following general items:

- Location with respect to point of wastewater collection/treatment facilities
- Compatibility of planned objectives with overall land use plan
- Proximity to surface waters
- Number and size of available land parcels

Important characteristics, such as climate, topography, vegetation, geology, and soils, are discussed by type of land application method in the next chapter.

SITE LOCATION

A topographic map (for example, USGS 7.5- or 15-minute quadrangles) can be used for initial site location. Distances and locations of potential transmission routes and elevation differences can be determined. In many cases, a tradeoff can be made between increasing costs for transmission and decreasing land values if the site is located in a sparsely developed outlying area.

COMPATIBILITY WITH OVERALL LAND USE PLAN

Planning documents, such as basin plans, areawide wastewater management plans, or regional management plans, should be consulted with regard to siting of wastewater treatment facilities. Land use planning is usually conducted at either the regional or the county level, and published plans should be investigated. Planning commissions and zoning authorities should be contacted to determine:

- If land application can be planned in a specific area
- What future population densities are planned for the area

- What the long-range planning objectives are for the area
- Which of these objectives can be integrated with land application

PROXIMITY TO SURFACE WATER

For overland flow systems and systems with underdrains or pumped withdrawal, discharge of renovated water to surface waters should be considered. Distance from receiving surface waters, as well as quality considerations, water rights, and the overall hydrology of the area, is important. Flood plain mapping (U.S. Army Corps of Engineers) should be consulted to determine if special protective provisions must be made in the design.

NUMBER AND SIZE OF AVAILABLE LAND PARCELS

The relative availablity of land at potential sites, together with the probable price per acre, must be defined early in the evaluation. The number and size of available parcels will be of significance, especially in relation to the complexity of land acquisition and control- a subject that is discussed on pages 39 and 40 of *Evaluation of Land Application Systems.*[9]

Chapter IV

SELECTION OF THE LAND APPLICATION METHOD

Selection of the appropriate land application method requires matching the management objectives and wastewater characteristics to the characteristics of potential sites, expected treatment efficiencies, and land requirements.

SITE EVALUATION

Criteria for climate, topography, soil, geology, hydrology, and vegetation vary with the type of land application method. Climatic and topographic criteria are discussed in the following paragraphs. Soil characteristics, groundwater conditions, and crop selection--mentioned briefly here--are discussed in Design Factors – II.

Climate

For irrigation of annual crops, wastewater application is restricted to the growing season, and storage may be required for a period ranging from 3 months in moderate climates to 7 months in cold northern states. Irrigation of perennial grasses or double cropping annual crops can extend the period of application. Periods of snow cover, intense rainfall, and subfreezing conditions may limit the application to perennial grasses and forestland. This depends on water quality criteria for the percolating water because the treatment efficiency of soil systems decreases under these conditions.

Infiltration-percolation is the method least affected by climate, particularly if flooded basins are used. The system at Lake George, New York, is operated year-round, with the relatively warm effluent being applied beneath a layer of ice during cold spells.[2]

Overland flow is similar to irrigation of perennial grasses in its response to climatic factors. Because infiltration of the applied water is minimal and the systems are designed for runoff, they may be operated during wetter weather than would be possible with irrigation systems. Operation at temperatures of 25 degrees Fahrenheit has been practiced; however, once operation ceases because of low temperatures, it is not started again until the temperature reaches about 40 degrees Fahrenheit.

Topography

Spray irrigation can generally be adapted to the existing wooded terrain if slopes are less than approximately 30 percent and runoff and erosion are controlled. For cultivated agriculture, the slopes should not exceed about 15 percent. For irrigation using standard long-span center pivot sprinkling systems, the slopes are generally limited to 15 to 20 percent.

Relatively flat land is normally required for surface irrigation, although contour furrows can be used with slopes as steep as 5 percent.

For infiltration-percolation systems, the primary concern with regard to topography is that lateral movement of water be controlled so that percolation rates of lower basins are not affected. At Westby, Wisconsin, basins have been terraced into a 5-percent sloping hillside, but there are no underdrains and the lateral movement of water from the upper basins affects the percolation rates in the lower basins.

For overland flow systems, the primary requirement is that the existing topography be such that terrace slopes of 2 to 8 percent can be economically formed. The cost and impact of the earthwork required would be the major constraints.

Geology and Soils

Although soil drainage cannot be predicted from soil type alone, a general indication of soil type versus ranges of liquid loading rates is shown in figure IV-1. It should be noted that the ranges in figure IV-1 denote typical practice and do not represent recommended loadings. Loamy soils are preferred for irrigation systems; however, most soils from sandy to clay loams are acceptable. Both the soil depth and minimum depth to groundwater should generally be at least 5 feet to ensure proper renovation and root development. The depth to groundwater can often be increased by underdrains or pumped withdrawal. Geologic discontinuities that may cause short-circuiting of applied water to the groundwater should be avoided.

Infiltration-percolation systems require well-drained soils, such as sands, sandy loams, loamy sands, and gravels. A depth of 10 to 15 feet to existing groundwater is preferred.[2] Lesser depths may be acceptable where underdrainage is provided.

Soils with limited drainability, such as clays and clay loams, are best suited for overland flow systems. Soil depth should be sufficient to form the necessary slopes and maintain a vegetative cover.

Vegetation

Existing vegetation can be analyzed to predict soil drainage and moisture-holding capacity. It may also reflect sodic (high sodium), saline (high dissolved solids), or infertile soil conditions.

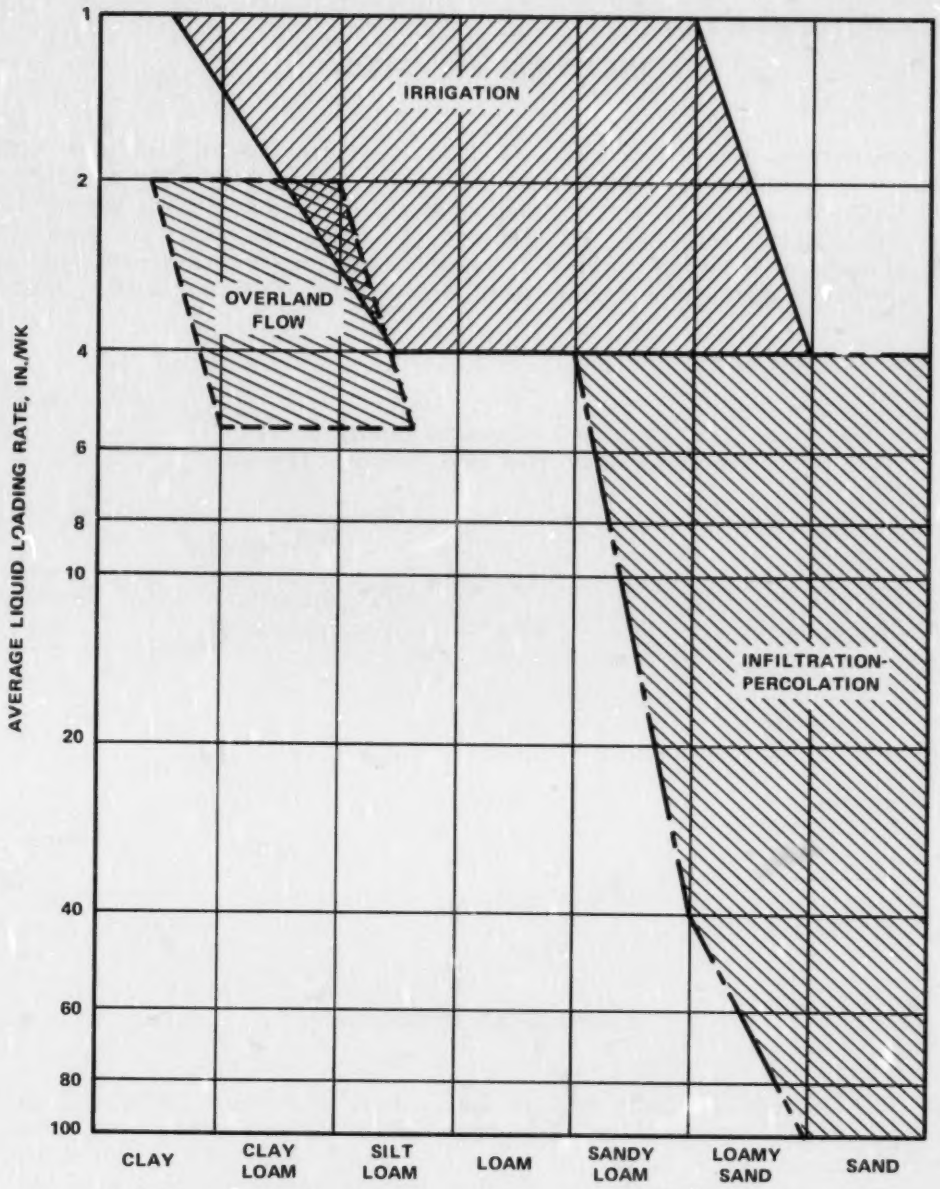

Figure IV-1. Soil type versus liquid loading rates for different land application approaches.[2]

Forested sites can be irrigated provided the stand is not so thick as to prevent efficient spray application. Clearing of sites is necessary for infiltration-percolation systems because the high application rates will kill most native vegetation. For overland flow, clearing is necessary to establish smooth slopes and to plant perennial, water-tolerant grasses.

TREATMENT EFFICIENCY

The expected treatment efficiencies of land treatment systems will vary with the concentrations of constituents in the applied wastewater. The quality of the water after land treatment, however, appears to be somewhat more consistent. Reed[11] has shown that the renovated water quality for BOD, nitrogen, and phosphorus is nearly the same whether untreated, primary, or secondary effluent is applied. The values for renovated water quality given in table IV-1 represent a typical range derived from Thomas,[3] Reed,[11] and other references.[2,7,9]

Table IV-1.–*Expected quality of renovated water from land treatment systems*

Constituent	Value, mg/l		
	Irrigation	Infiltration-percolation	Overland flow
BOD	1-2	2-5	5-10
Suspended solids	1-2	1-2	8-10
Ammonia nitrogen as N	0.5-1	0.5-1	0.5-1
Total nitrogen as N	2-4	10-15	2-5
Phosphorus as P	0.1-0.5	1-3	3-5

LAND AREA REQUIRED

The total amount of land required for a land application system–though highly variable–is primarily dependent on application rates. Other features that affect land requirements include buffer zones, storage, access roads, dikes, flood control structures, terraces, fencing, and an administration building. Because application rates vary significantly for each land application method, the land area required for each one will be given as a typical range.

The total land required for a 1-mgd irrigation system can vary from 60 to 500 acres, with 100 to 200 acres being the typical range. Buffer zones (unirrigated strips of land around sites) are frequently required for sprinkling systems and can increase the total land requirement significantly, particularly in cases where the land requirement is otherwise small.

Infiltration-percolation is the least land-intensive method of application. High-rate systems may require as little as 3 to 6 acres per mgd, while low-rate systems may require 20 to 60 acres per mgd.

Land requirements for overland flow systems typically range from 25 to 110 acres per mgd. As with spray irrigation, this range may be increased if buffer zones are required.

Chapter V

DISTRIBUTION TECHNIQUES

As many as 20 distribution techniques for water are available for engineered wastewater effluent applications. Many of the techniques developed in the irrigation industry have not been applied to wastewater. Drip irrigation, for example, would require a filtered effluent for crop irrigation and is therefore not an economical technique for wastewater. Other techniques described by Pair[12] may be applicable to wastewater application and should be investigated with regard to economics, efficiency, operation and maintenance, and reliability.

IRRIGATION

Distribution techniques for irrigation can be classified into three main groups: fixed sprinkling systems, moving sprinkling systems, and surface application systems. Detailed criteria on these systems are available in Pair[12] and other sources.[13,14]

Fixed Sprinkling Systems

Fixed sprinkling systems, often called solid set systems, may be either on the ground surface or buried. Both types usually consist of impact sprinklers on risers that are spaced along lateral pipelines, which are in turn connected to main pipelines. These systems are adaptable to a wide variety of terrains and may be used for irrigation of either cultivated land or woodlands.

Above-ground systems normally use portable aluminum pipe, which has the advantage of a relatively low capital cost. Several serious disadvantages of surface aluminum pipe are:

- It is easily damaged.
- It has a short expected life due to corrosion.
- It must be moved during cultivation and harvesting operations.

Plastic or asbestos cement pipe is most often used for buried systems. Laterals may be buried as deep as 1.5 feet, and main pipelines, 2.5 to 3 feet below the surface. Buried systems generally have the greatest capital cost of any of the irrigation systems. On the other hand, they are probably the most dependable, and they are well suited to automatic control.

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Sprinkler spacings, application rates, nozzle sizes and pressures, control systems, risers, and drain valves are the major design parameters in fixed sprinkling systems. General practice is as follows:

- Sprinkler spacing–May vary from 40 by 60 feet to 100 by 100 feet and may be rectangular, square, or triangular. Typical spacings are 60 by 80 feet and 80 by 100 feet.

- Application rate–May range from 0.10 to 1 in./hr or more, with 0.16 to 0.25 in./hr being typical. Application rate is calculated using equation (1):

$$\text{Application rate, in./hr} = \frac{96.3Q \text{ (gpm per sprinkler)}}{\text{Area (sq ft covered)}} \qquad (1)$$

Sample calculation: Determine the application rate for a spacing of 80 by 80 feet and a discharge per sprinkler head of 15 gpm.

$$\text{Application rate} = \frac{96.3\ (15)}{(80)\ (80)} = 0.23 \text{ in./hr}$$

- Nozzles–Generally vary in size of openings from 0.25 inch to 1 inch. The discharge per nozzle can vary from 4 to 100 gpm, with a range from 8 to 25 gpm being typical. Discharge pressures can vary from 30 to 100 psi, with 50 to 60 psi being typical. Single-nozzle sprinklers are preferred because of lesser clogging tendencies and larger spray diameters.

- Control systems–May be automatic, semiautomatic, or manual. Automatic systems are the most popular for land application systems. Automatic valves may be either hydraulically or electrically operated.

- Risers–May be galvanized pipe or PVC of sufficient height to clear the crop, usually 3 to 4 feet for grass. The riser should be adequately staked because impact sprinklers cause vibrations that must be damped.

- Drain valves–Should be located at low points in lines, with gravel pits to allow water to drain away and prevent in-line freezing.

Moving Sprinkling Systems

There are a number of different moving sprinkling systems, including center pivots, side roll wheel move, rotating boom, and winch-propelled sprinkling machines. The center pivot system is the most widely used for wastewater irrigation and is the only system discussed here. General practice with respect to sizes, propulsion, pressures, and topography is as follows:

- Sizes–Center pivot systems consist of a lateral that may be 600 to 1,400 feet long, which is suspended by wheel supports and rotates about a point. Areas of 35 to 135 acres can be irrigated per unit.

- Propulsion–By means of either hydraulic or electric drive. One rotation may take from 8 hours to as much as 1 week.

- Pressures–Usually 50 to 60 psi at the nozzle, which may require 80 to 90 psi at the pivot. Standard sprinkler nozzles or spray heads directed downward can be used.

- Topography–Can be adapted to rolling terrain up to 15 to 20 percent.

Surface Application Systems

The two main types of surface application systems are ridge and furrow, and border strip flooding irrigation.

Ridge and furrow irrigation is accomplished by gravity flow of effluent through furrows from which it seeps into the ground. General practice is as follows:

- Topography–Can be used on relatively flat land (less than 1 percent) with furrows running down the slope, or on moderately sloped land with furrows running along the contour.

- Dimensions–Furrow lengths usually range from 600 to 1,400 feet. Furrows are usually spaced between 20 and 40 inches apart, depending on the crop.

- Application–Usually by gated aluminum pipe. Short runs of pipe (80 to 100 feet) are preferred to minimize pipe diameter and headloss and to provide maximum flexibility. Surface standpipes are used to provide the 3 to 4 feet of head necessary for even distribution.

Border strip irrigation consists of low, parallel soil ridges constructed in the direction of slope. The major design variables for surface flooding using border strips include strip dimensions, method of distribution, and application rates. General practice is as follows:

- Strip dimensions–Vary with type of crop, type of soil, and slope. Border widths may range from 20 to 100 feet; 40- to 60-foot widths are the most common. Slopes may range from 0.2 to 0.4 percent. The steeper slopes are required for relatively permeable soils. Strip length may vary from 600 to 1,400 feet.

- Method of distribution–Generally by means of either concrete-lined ditch with slide gates at the head of each strip, underground pipe with risers and alfalfa valves, or gated aluminum pipe.

- Application rates–At the head of each strip, will vary primarily with soil type and may range from 10 to 20 gpm per foot width of strip for clay to 50 to 70 gpm per foot width of strip for sand. The period of application for each strip will vary with strip length and slope.

INFILTRATION-PERCOLATION

Intermittent flooding in basins is the most common distribution method, although high-rate spraying (more that 4 in./wk) may also be used. With flooding basins, the major design variables include application rate, basin size, height of dikes, and maintenance of basin surfaces. General practice is as follows:

- Application rates and cycles–Rates can vary from 4 to 120 in./wk, as discussed in Design Factors – II. Loading cycles generally vary from 9 hours to 2 weeks of wetting followed by 1 day to 3 weeks of drying.

- Basin size–Generally a function of design flow and relationship of wetting and drying periods. Basins may range in size from less than 1 acre to 10 acres or more. It is usually necessary to include at least two separate basins for even the smallest systems.

- Height of dikes–Will vary with depths of water applied. For depths of 1 to 2 feet, a height of approximately 4 feet is common.

- Maintenance of basin surface–Many systems require periodic tilling of the surface, often annually, while some high-rate systems may require periodic replacement of the sand or gravel.

OVERLAND FLOW

Sprinkling is the most common technique in the United States; however, surface flooding may be practicable for effluents relatively low in suspended solids. General practice is as follows:

- Sprinkler application–Either fixed sprinklers or rotating boom-type sprays may be used. Moving or portable systems are not practicable as a smooth surface must be maintained. Sprinklers are spaced from 60 to 80 feet apart on the laterals.

- Slopes–Slopes may range from 2 to 8 percent with 2 to 4 percent preferred for adequate detention time. Lengths of slope may range from 150 to 300 feet, with 175 to 250 feet being typical.

- Application rates and cycles–Rates range from 2 to 10 in./wk, with 3.5 to 5.5 in./wk being typical. Common cycles are 6 to 8 hours of wetting and 16 to 18 hours drying to maintain the microorganisms on the soil surface active.

- Surface application–May be by flooding or by gated pipe. Most suited to wastewater low in organic solids.

Chapter VI

CLIMATIC FACTORS AND STORAGE

An evaluation of climatic factors, such as precipitation, evapotranspiration, and temperature, is important primarily for the determination of the water balance, length of the growing season, number of days when the system cannot be operated, and the storage capacity requirement. Another important function of the climatic factors is stormwater runoff control, which will be discussed in the next chapter. Climatic data, storage requirements, the water balance, and a computer program to determine storage using climatic data are discussed in this chapter.

CLIMATIC DATA

Sufficient climatic data are generally available for most locations in the country from three publications of the National Oceanic and Atmospheric Administration (formerly the Weather Bureau).

The *Monthly Summary of Climatic Data* provides basic data, such as total precipitation, maximum and minimum temperatures, and relative humidity, for each day of the month for every weather station in a given area. Evaporation data are also given where available.

The *Climatic Summary of the United States* provides 10-year summaries of data for the same stations in the same given areas. This form of the data is convenient for use in most of the evaluations that must be made, and includes:

- Total precipitation for each month of the 10-year period
- Total snowfall for each month of the period
- Mean number of days with precipitation exceeding 0.10 and 0.50 inch for each month
- Mean temperature for each month of the period
- Mean daily maximum and minimum temperatures for each month
- Mean number of days per month with temperature less than or equal to 32 degrees Fahrenheit, and greater than or equal to 90 degrees Fahrenheit

Local Climatological Data, an annual summary with comparative data, is published for a relatively small number of major weather stations. Among the more useful data contained in the publication are the normals, means, and extremes which are based on all data for that station, on record to date. To use such data, correlation may be required with a station reasonably close to the site.

Data on evapotranspiration are often more difficult to obtain, particularly in the East. When evaporation data are available, evapotranspiration can be predicted using empirical equations. In other cases, values of net evapotranspiration obtained from the map shown in figure VI-1 are often sufficient.

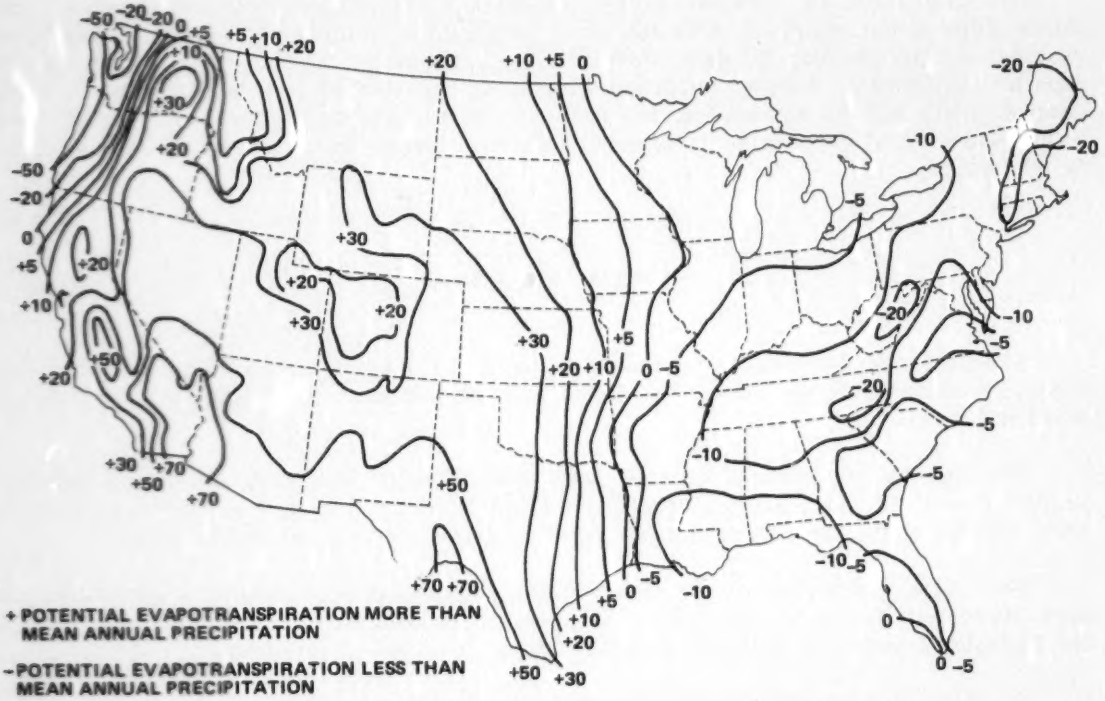
+ POTENTIAL EVAPOTRANSPIRATION MORE THAN MEAN ANNUAL PRECIPITATION
- POTENTIAL EVAPOTRANSPIRATION LESS THAN MEAN ANNUAL PRECIPITATION

Figure VI-1. Potential evapotranspiration versus mean annual precipitation (inches).[15]

STORAGE REQUIREMENTS

Climate affects the operation of each land application method differently. Storage requirements because of climate are discussed for each method.

Irrigation

Storage requirements for systems that irrigate annual crops are primarily dependent on the growing season of those crops, which in turn is dependent on the local climate. The minimum storage requirement would then be equal to the flow over the remaining portion of the year. In many areas with mild or moderate climates, two annual crops can be grown each year, which of course will reduce the storage requirement.

The storage requirements for systems that irrigate perennials, including woodlands, are normally related directly to climatic factors. Days on which application must be suspended can be predicted from an evaluation of the number of days when:

- The temperature is below a certain level.
- Precipitation exceeds a certain amount.
- Snow cover exceeds a certain depth.

With regard to temperature, it has been shown that irrigation systems can usually operate successfully below 32 degrees Fahrenheit. The most common lower limit is 25 degrees Fahrenheit. At least two methods are available for predicting the number of days that are too cold for operation. In the first method, it is assumed that application is suspended on all days in which the mean temperature is below 32 degrees Fahrenheit. This method is probably conservative, but it has the advantage of using readily accessible data. In the second method, which has been used successfully for some spray systems, it is assumed that application is suspended on days in which the minimum temperature is below 25 degrees Fahrenheit and is not resumed until the maximum daily temperature exceeds 40 degrees Fahrenheit. Half-day operation is assumed for days on which the minimum temperature is below 25 degrees Fahrenheit and the maximum exceeds 40 degrees Fahrenheit.

The maximum precipitation allowed before application is stopped will depend primarily on the maximum infiltration rates at the site and stormwater runoff considerations. At sites with limited infiltration rates and where stormwater runoff is of concern, as little as 0.2 inch of precipitation in a day may require suspension of application. In other cases, full-time operation may be assumed during days with 1.0 inch or more of precipitation.

Irrigation of perennial grasses and woodlands can be conducted during snow cover provided renovation is not critical under these conditions. When the built-up ice and snow melt, the runoff must be contained. The persistence of snow on the field is important to consider because snow that melts quickly is no more of a problem than rainfall.

Infiltration-Percolation

For high-rate spraying systems, the storage design factors are generally similar to those for irrigation of perennial crops, except that storage is seldom required for days with high amounts of precipitation.

Intermittent flooding systems using infiltration basins can often be operated continuously and seldom require any significant storage, except possibly for system backup or extremely severe climatic conditions.

Overland Flow

The storage design factors for overland flow are similar to those for irrigation of perennial crops, with one significant difference—that related to precipitation. This difference is a result of the fact that applied water is collected after treatment. If runoff is to be strictly controlled or disinfected after collection, maximum daily application rates allowable during precipitation may be relatively small. On the other hand, if the wastewater is sufficiently treated and disinfected prior to application, stormwater runoff might not be of special concern, and storage requirements for periods of precipitation might be reduced.

WATER BALANCE

The water balance for land application systems is described by the equation:

$$\text{Design precipitation} + \text{Effluent applied} = \text{Evapotranspiration} + \text{Percolation} + \text{Runoff}$$

For most irrigation and infiltration-percolation systems, runoff will be zero. In high-rate infiltration-percolation systems, precipitation and evapotranspiration will be of little significance compared with effluent applied and percolation. In overland flow systems, percolation will be minimal, and runoff may represent 40 to 80 percent of the effluent applied.

If used on a monthly, weekly, or daily basis, the balance can be used to calculate cumulated storage, with the maximum value over the year being the required capacity. In this process, the term for effluent applied should reflect reduced operating time resulting from adverse climatic conditions and increases during drawdown of storage. The method is illustrated in Example 1.

Example 1: Determine the storage requirements from a monthly water balance for a 1-mgd irrigation system.

Assumptions

1. Design precipitation and evapotranspiration are for the wettest year in 25, with average monthly distribution.
2. A perennial grass is grown and irrigated year-round.
3. Nitrogen is limiting, and the area required as a result of the nitrogen balance is 120 field acres.
4. Runoff is contained and reapplied.
5. The design year begins in October with the storage reservoir empty.

Solution

Computations and results are presented in table VI-1.

Table VI-1.—*Example of storage determination from water balance for irrigation (inches)*

Month (1)	Evapo-trans-piration (2)	Perco-lation (3)	Water losses (2) + (3) = (4)	Precipi-tation (5)	Effluent applied (6)	Effluent available (7)	Total water available (5) + (7) = (8)	Change in storage, (8) - (4) = (9)	Total storage (10)
Oct	2.3	10.0	12.3	1.6	10.7	9.3	10.9	-1.4	0
Nov	1.0	10.0	11.0	2.4	8.6	9.3	11.7	.7	.7
Dec	0.5	5.0	5.5	2.7	2.8	9.3	12.0	6.5	7.2
Jan	0.2	5.0	5.2	3.0	2.2	9.3	12.3	7.1	14.3
Feb	0.3	5.0	5.3	2.8	2.5	9.3	12.1	6.8	21.1
Mar	1.1	10.0	11.1	3.4	7.7	9.3	12.7	1.6	22.7
Apr	3.0	10.0	13.0	3.0	10.0	9.3	12.3	-.7	22.0
May	3.5	10.0	13.5	2.1	11.4	9.3	11.4	-2.1	19.9
Jun	4.8	10.0	14.8	1.0	13.8	9.3	10.3	-4.5	15.4
Jul	6.0	10.0	16.0	0.5	15.5	9.3	9.8	-6.2	9.2
Aug	5.7	10.0	15.7	1.1	14.6	9.3	10.4	-5.3	3.9
Sep	3.9	10.0	13.9	2.0	11.9	9.3	11.3	-2.6	1.3
Total annual	32.3	105.0	137.3	25.6	111.7	111.8	137.2		

1. Precipitation and evapotranspiration data are entered into columns 5 and 2, respectively.

2. On the basis of the nutrient balance, the design allowable percolation rate is 10 in./mo from March through November and 5 in./mo for the remaining months (column 3).

3. The water losses (column 4) are found by summing evapotranspiration and percolation.

4. The effluent applied (column 6) is the difference between the water losses and the precipitation.

5. The effluent available per month (column 7) is:

$$\text{Effluent available} = \frac{1 \text{ mgd} \times 30.4 \text{ day/mo} \times 36.8 \text{ acre-in./mil gal.}}{120 \text{ acres}}$$

6. The total water available (column 8) is the sum of effluent available and precipitation.

7. The monthly change in storage (column 9) is the difference between the total water available (column 8) and the water losses (column 4).

8. The total accumulated storage (column 10) is computed by summing the monthly change in storage.

9. The maximum storage is 22.7 inches occurring in March. This is equivalent to a storage volume of:

$$\text{Storage volume} = \frac{(22.7 \text{ in.})\ (120 \text{ acre})}{12 \text{ in./ft}} = 227 \text{ acre-ft}$$

10. The effluent applied is 111.7 inches (9.3 feet) on an annual basis with about 3.5 in./wk applied as the maximum rate in July.

Comments

1. The maximum storage volume of 227 acre-feet would be the equivalent of 74 days' flow at 1 mgd.

2. If a significant amount of storage remained at the end of the period (i.e., in September), it could be reduced by increasing the field area to more than 120 acres, or increasing the design amount of percolation. However, increases in design percolation rates would require reevaluation of nitrogen loading rates.

3. The accuracy of the water balance method can be improved if a time increment smaller than a month (weekly or daily water balances) is used.

4. An alternative method for computing storage requirements from the water balance is to calculate a series of water balances for each year of a period of record (at least 10 to 20 years). The design storage requirements for the worst year in 25 could then be determined by means of a frequency analysis of the storage requirements for each year.

COMPUTER PROGRAM

A computer program, which relates many of the factors described previously in this chapter, has recently become available through the National Climatic Center in Asheville, North Carolina.[16] It utilizes basic daily climatic data for a given weather station, for a given period of years, and identifies which days are unfavorable for application. The total storage capacity required each year can be calculated by adding one day's flow to storage each unfavorable day. Storage is then reduced by some fraction of a day's flow (based on the

actual drawdown rate) for each favorable day. The maximum storage capacity is then identified for each year. A simplified example printout for a portion of a month is shown in table VI-2.

Table VI-2.–*Sample printout of climatic data program*

Year	Month	Day	Temperature, deg F			Snow depth, in.	Precipitation, in.	Favorable day	Unfavorable day[a]	Storage, days
			Maximum	Minimum	Mean					
55	02	01	42	28	35	–	.01	X		
55	02	02	34	17	26	3	.45		X	1
55	02	03	33	7	20	2	–		X	2
55	02	04	19	6	13	2	–		X	3
55	02	05	31	11	21	2	–		X	4
55	02	06	46	30	38	T	.95		X	5
55	02	07	48	32	40	–	.05	X		4.5[b]
55	02	08	49	19	34	–	–	X		4
55	02	09	20	9	15	–	–		X	5
55	02	10	44	28	36	–	–	X		4.5

[a]Definition of unfavorable day:
Mean temperature $\leq$ 32 deg F
Precipitation $\geq$ 0.50 in.
Snow depth $\geq$ 1 in.

[b]Drawdown rate from storage on favorable days is 0.5 x daily flow; i.e., on favorable days the amount actually applied to the field is the average daily flow plus an extra 50 percent from storage.

Chapter VII

SURFACE RUNOFF CONTROL

Requirements for control of surface runoff resulting from both applied effluent and stormwater depend mainly on the expected quality of the runoff—for which few data exist. Considerations relating to surface runoff control are discussed here for both irrigation and overland flow systems. Infiltration-percolation systems are not included in the discussion because, in almost all cases, these systems are designed so that no runoff is allowed.

IRRIGATION SYSTEMS

Surface runoff control considerations for irrigation systems can be divided into tailwater return, storm runoff, and system protection.

Tailwater Return

Surface runoff of applied effluent is usually designed into surface application systems, such as ridge and furrow and border strip flooding, because it is difficult to maintain even distribution across the field with these methods, and some excess water may accumulate at the end of furrows or strips. Generally, this tailwater is returned by means of a series of collection ditches, a small reservoir, a float-actuated pumping station, and a force main to the main storage reservoir or distribution system.

The most common range of flows for tailwater is between 5 and 25 percent of applied flows (depending on the management provided, the type of soil, and the rate of application). In humid climates, the tailwater system design may be controlled by stormwater runoff flows. A more detailed discussion of storm runoff follows in the next paragraph.

Storm Runoff

For high intensity rainfall events, some form of storm runoff control may be required for irrigation systems, except those with well-drained soils, relatively flat sites, or where the quality of the runoff is acceptable for discharge. Where runoff control is deemed necessary, it generally consists of the collection and return of the runoff from a storm of specified

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intensity, with a provision for the overflow of a portion of all larger flows. Questions the designer must answer include:

- How much precipitation will run off?
- What will the quality of the runoff be?
- How much runoff must be contained and reapplied?

The amount of runoff to be expected as a result of precipitation will depend on:

- Infiltration capability of the soil
- Antecedent moisture condition of the soil
- Slope
- Type of vegetation
- Temperature of both air and soil

The relationships between runoff and these factors are common to many other hydrologic problems and are adequately covered by Viessman.[17]

Runoff quality during storms is essentially unknown for most parameters. To give some perspective to the magnitude of nitrogen and phosphorus concentrations measured in runoff from various rural areas, and until quantitative data from effluent-applied sites are available, the average values given in table VII-1 may be useful.

It is important to note that the research work reported in table VII-1 was aimed primarily at fertilizing practice and cultivation versus noncultivation as related to nutrient losses. Other factors in sediment and nutrient loss include contour planting versus straight-row planting and incorporation of plant residues to increase organic matter in the soil. In each research study, many additional factors that affect erosion losses were presented, and the interested reader should consult the literature.

The question of how much runoff should be contained or reapplied is difficult to answer. The answer depends on the quality of runoff, water quality of the stream during storms, and downstream uses of the water, as well as on rural runoff control objectives within the hydrologic basin. Difficulties will remain until sufficient research has been completed to define the problem. Therefore, in the interim, some provision should be made for limited storm runoff control from irrigation systems. This should consist of capturing and recycling the first flush from the field, as a minimum. It might range from capturing the first 30 minutes to all of the flow resulting from a 2-year frequency storm event.

System Protection

An additional requirement for runoff control often results from the need for protection from runoff caused by system failures. System failures may include ruptured sprinkler lines,

Table VII-1.—*Average values of nitrogen and phosphorus measured in rural stormwater runoff studies*

Location and site description	Management practice	Total nitrogen, mg/l	Total phosphorus, mg/l	Reference
North Carolina	Heavily fertilized, uncultivated	4.60	0.10	18
	Lightly fertilized, uncultivated	1.60	0.08	
Cornell (corn, beans, wheat)	Highly fertilized	6.17[a]	0.26[b]	19
	Moderately fertilized	1.70[a]	0.12	
Ontario (marsh)	Fertilized and cultivated	1.88[c]	0.67	20
	Unfertilized and uncultivated	0.05[c]	0.17	
Wisconsin (pilot plots, oat stubble)	Fertilized, plowed surface			21
	1. In sediment	81.8[d]	0.88	
	2. In water	2.8	0.49	
		84.6	1.37	
	Unfertilized plowed surface			
	1. In sediment	75.2	0.33	
	2. In water	0.7	0.10	
		75.9	0.43	

[a]Ammonia plus nitrate nitrogen only.
[b]Inorganic phosphorus only.
[c]Nitrate plus nitrite nitrogen only.
[d]Organic nitrogen from soil sediment accounted for 90+% of all nitrogen. Runoff occurred from 1 hr of rain at 2.5 in./hr 24 hr after a similar rain event.

inadvertent overapplication, or soil sealing as a result of wastewater constituents or frost. The requirements under this objective would probably be satisfied as part of the storm runoff control system.

OVERLAND FLOW SYSTEMS

Significantly, more extensive runoff control features are normally required for overland flow than for irrigation systems, because overland flow systems are designed principally for runoff of applied effluent rather than percolation. Typically, 40 to 80 percent of the applied effluent runs off. The remainder is lost to percolation and evapotranspiration. In most cases, the runoff is collected in ditches at the toe of each terrace and then conveyed by open channel or gravity pipe to a discharge point, where it is monitored and, in some cases, disinfected. Discharge may be to surface waters, to reuse facilities, or sometimes to additional treatment facilities such as infiltration-percolation.

Storm runoff presents some special problems. Under conditions of light precipitation (on the order of 0.05 to 0.10 in./hr), most overland flow systems can be operated as usual. Although there is little documentation of the fact, the quality of runoff from greater amounts of precipitation should improve as a result of dilution, provided erosion is not caused. For the overland flow system at Paris, Texas, rainfall events of 0.1 to 2.0 inches increasingly reduced from normal levels the effluent conductivity in the runoff.[22] (Effluent conductivity was the only constituent recorded under these conditions.) Pathogenic organisms in the runoff should not generally cause serious problems if the effluent is disinfected before application, as they do not normally regrow in the field.

Chapter VIII

PUBLIC HEALTH CONSIDERATIONS

Public health aspects are related to the following:

- Pathogenic bacteria and viruses present in municipal wastewater and their possible transmission to higher biological forms, including man
- Chemicals that may reach the groundwater and pose dangers to health if ingested
- Crop quality when irrigated with wastewater effluents
- Propagation of insects that could be vectors in disease transmission

PATHOGENS

The survival of pathogenic bacteria and viruses in sprayed aerosol droplets, on and in the soil, and the effects on workers have received considerable attention. It is important to realize that any connection between pathogens applied to land through wastewater and the contraction of disease in animals or man would require a long and complex path of epidemiological events. Nevertheless, questions have been raised, concern exists, and precautions should be taken in dealing with possible disease transmission.

Aerosols

Effluents applied by sprinklers will produce a mist, often referred to as drift, that may be transported by wind currents. Mist droplets that are extremely small in both dimension and mass are referred to as aerosols. Aerosols are tiny airborne colloidal-like droplets of liquid (0.01 to 50 microns in diameter). Aerosols generated in connection with inadequately disinfected wastewater contain active bacteria and viruses. Sorber[23] found that the median size of viable particles collected downwind from effluent spray was 5 microns. This is important because this size of particle is subject to inhalation by humans. He also reported that aerosolization occurred for only about 0.3 percent of the wastewater being sprinkled, as determined by fluorescein tracer tests.

Infectivity of a biological aerosol is dependent on the depth of respiratory tract penetration. Particles of the 2- to 5-micron size range are primarily captured in the upper respiratory tract and may ultimately pass to the digestive tract. Sizes in the 1- to 2-micron

size may be inhaled into the lungs. Infectivity is most probable in the latter case. Therefore, particle size distribution is an important factor in evaluating aerosol-borne pathogens.

The travel of aerosols and the effect of chlorination on bacterial levels in aerosols was also studied by Sorber.[23] Unchlorinated trickling filter effluent was discharged at 100 psi through a 1/2-inch diameter Rainbird sprinkler. The study was performed in Arizona. With wind velocities of 5.7 mph, viable coliforms were found at a distance of 500 feet. The effect of wind is significant in aerosol production; however, Sorber found that the concentration of coliforms in aerosols downwind from the sprinkler increased for lower wind velocities. In fact, under stable atmospheric conditions (low wind velocities and night time), Sorber estimated that a travel distance of over 1 mile would be necessary to reduce the concentration of viable organisms to background levels. Sorber therefore concluded that relying on buffer zones alone to reduce aerosol activity is impractical.

When the secondary effluent in this study was chlorinated, only one viable coliform per cubic meter of air was found in the downwind samples. Chlorine contact time was longer than normal (45 minutes), and the total chlorine residual was 0.8 mg/l. This disinfection procedure resulted in a total concentration of 220 viable particles per milliliter in the wastewater before sprinkling. Sorber concluded that the most important factors bearing on the downwind aerosol concentrations observed are the concentration of organisms sprayed and the atmospheric stability.[23]

In other studies on aerosol particles, it was found that as the relative humidity decreased and air temperature increased, the death rate of bacteria increased.[24] Sorber[25] indicated that a 50-micron water droplet will evaporate in 0.31 second in air, with 50-percent relative humidity and a temperature of 22 degrees Centigrade. Thus, dessication is a major factor in bacterial die-off. Dessication effects are limited by the number of aerosol-size particles in the effluent before sprinkling.

Finally, although much remains to be determined in investigating aerosols and their potential infectivity, some safeguards can be established. Among these are disinfection, sprinklers that spray horizontally or downward with low nozzle pressure, and adequate buffer zones. Although buffer zones may be relatively ineffective in reducing the strength of aerosols, they are effective in containing the drift of spray mist which is aesthetically unpleasing. Buffer zones that have been required by some states range from 50 feet to 1/4 mile around a site.[26] Low-trajectory nozzles and screens of trees and shrubs can be used to limit mist travel. The travelling rig sprinklers designed for Muskegon, Michigan, have been modified to direct the spray trajectory downward. Studies of aerosol drift are being planned for the Muskegon operation.[27]

Survival in Soil and on Vegetation

The survival time of pathogenic organisms in the soil can vary from days to months, depending on the soil moisture, soil temperature, and type of organism. Sepp[26] and Dunlop[28] have prepared extensive tabulations of survival times of various organisms in soil, in water, and on vegetation. A portion of these tabulations is shown in table VIII-1. It should be noted that the survival times reported are not from irrigation systems applying treated municipal wastewater.

Table VIII-1.—*Survival times of organisms*[26,28]

Organism	Medium	Type of application	Survival time
Ascaris ova	Soil	Sewage	Up to 7 years
	Vegetables	AC[a]	27-35 days
B. Typhosa	Soil	AC	29-70 days
	Vegetables	AC	31 days
Cholera vibrios	Spinach, lettuce	AC	22-29 days
	Nonacid vegetables	AC	2 days
Coliform	Grass	Sewage	14 days
	Tomatoes	Sewage	35 days
Endamoeba histolytica	Vegetables	AC	3 days
	Soil	AC	8 days
Hookworm larvae	Soil	Infected feces	6 weeks
Leptospira	Soil	AC	15-43 days
Polio virus	Polluted water	—	20 days
Salmonella typhi	Radishes	Infected feces	53 days
	Soil	Infected feces	74 days
Shigella	Tomatoes	AC	2-7 days
Tubercle bacilli	Soil	AC	6 months
Typhoid bacilli	Soil	AC	7-40 days

[a]AC—Artificial contamination.

Survival time of organisms outside their natural habitat depends on the initial concentration, humidity, amount of sunlight, type of soil, type of organism, and type of medium. In relation to survival of coliform organisms, some bacteria do survive for a longer time in soil. The survival of viruses in soil is essentially unexplored.[27]

EFFECTS ON WORKERS

The effects of working around and handling wastewater on land application sites are minimal. Using reasonable habits of personal hygiene, the health hazards appear to be no different than for activated sludge and trickling filter plants. Benarde[29] cites several case

histories with conclusions that, if handled with care, sewage effluent is not hazardous to the personnel.

Work referenced in Sorber's paper[25] indicates that spraying of chlorinated effluent for landscape watering resulted in approximately 1.5 times the number of viable biological aerosols emitted by a trickling filter. Napolitano et al.[30] concluded that activated sludge plants yield approximately 10 times as many coliform-bearing aerosol particles as do trickling filter plants. In order to put numbers into perspective, a comparison was made between results obtained by Sorber versus those obtained by Napolitano, insofar as the data can be considered compatible. With the samplers located 150 feet from the source of aerosols, Sorber reported a mean of 6 viable coliforms per cubic meter of air sampled from a chlorinated and sprinkled trickling filter plant effluent, whereas Napolitano reported a range of 7 to 380 coliform colonies per cubic meter of air sampled downwind from an activated sludge aeration tank. He also reported a range of 7 to 140 colonies per cubic meter of air sampled downwind from a trickling filter plant. Of course, the relative humidity, wind velocity, and temperature were different for the various tests. Both investigators reported that the median viable particle size was about 5 microns; therefore, the particles are equally subject to inhalation by humans.

In short, no specific number can be given for quantifying health hazards at either land application or conventional treatment plants. Dixon and McCabe[31] cited several known cases of illness associated with conventional wastewater treatment plant activities and found no conclusive evidence that the overall health risks are higher for operators than for the public at large.

GROUNDWATER QUALITY

The proposed EPA regulations on interim primary drinking water standards are listed in table VIII-2. Both nitrates and total dissolved solids can present health hazards if they are present in high concentrations in groundwater that is used as a water supply. Because nitrate has been demonstrated to be the causative agent of methemoglobinemia in children, its concentration in drinking water is limited in the standards to 10 mg/l as nitrate nitrogen. A total dissolved solids limitation of 750 mg/l in drinking water is recommended by Sorber because high values of total dissolved solids can be harmful to people with cardiac, viral, or circulatory diseases.[27]

Solids contained in wastewater effluents will be filtered from the water in the upper layer of soil. Inorganic chemical constituents, such as trace metals, are usually removed from the percolating water by adsorption or chemical precipitation within the first few feet of soil. However, the concentrations of trace elements are usually below those limits set forth in the drinking water standards before application. Trace organics are also usually below the established limits before application. If there is any possibility that some particular constituent is abnormally high, at least two analyses should be made before recommending the design parameters. Bacterial removal from effluents passing through fine soils is quite complete. However, this may not be true in coarse sandy or gravelly strata that are used for high-rate infiltration systems. Fractured rock or limestone cavities may also provide a passage for bacteria that can travel several hundred feet from the point of application. Both of these latter cases deserve special consideration by the designer.

Table VIII-2.—*EPA proposed regulations on interim primary drinking water standards, 1975*[32]

Constituent or characteristic	Value	Reason for standard
Physical		
Turbidity, units	1[a]	Aesthetic
Chemical, mg/l		
Arsenic	0.05	Toxic
Barium	1.0	Toxic
Cadmium	0.01	Toxic
Carbon chloroform extract	0.7	Toxic
Chromium, hexavalent	0.05	Toxic
Cyanide	0.2	Toxic
Fluoride	1.4-2.4[b]	Toxic
Lead	0.05	Toxic
Mercury	0.002	Toxic
Nitrates as N	10	Toxic
Selenium	0.01	Toxic
Silver	0.05	Cosmetic
Bacteriological		
Total coliform, per 100 ml	1	Disease
Pesticides, mg/l		
Chlordane	0.003	Toxic
Endrin	0.0002	Toxic
Heptachlor	0.0001	Toxic
Heptachlor epoxide	0.0001	Toxic
Lindane	0.004	Toxic
Methoxychlor	0.1	Toxic
Toxaphene	0.005	Toxic
2,4-D	0.1	Toxic
2,4,5-TP	0.01	Toxic

[a]Five mg/l may be substituted if it can be demonstrated that it does not interfere with disinfection.
[b]Dependent upon temperature; higher limits for lower temperatures.

In summary, the most common public health concerns for land treatment systems are nitrogen and high total dissolved solids contamination of groundwater aquifers used for water supply.

CROP QUALITY

Few data exist on the quality of crops grown on wastewater effluents relative to those obtaining water and nutrients from other sources. Data from crops grown on sludge are not applicable because trace elements are several times higher in sludges than in effluents.

Data presented in table VIII-3 are for grasses at the land application site in Melbourne, Australia.[33] The authors collected green forage samples from grasses on nonirrigated (control) areas and in areas irrigated for 60 years with sedimented wastewater. All constituents in the plants, except nickel, are below the suggested tolerance limits proposed by Melsted.[34] The authors concluded that since nickel is poorly absorbed from ordinary diets and is relatively nontoxic, it would not pose a health problem to animals.[35]

A second example is presented in table VIII-4 which presents tissue analysis from leaves of corn grown on land that has been irrigated by effluent for 5 years. All values measured were below suggested tolerance levels except for cadmium. The data indicate values below 5 but do not indicate how far below 5.

Table VIII-3.—*Crop quality at Melbourne, Australia, compared to suggested tolerance levels for heavy metals*

Constituent	Grasses at Melbourne		Suggested tolerance levels, ppm
	Control sample, ppm	Wastewater irrigated, ppm	
Cadmium	0.77	0.89	3
Cobalt	<0.64	0.64	5
Copper	6.5	12	150
Iron	970	361	750
Manganese	149	49	300
Nickel	2.7	4.9	3
Lead	<2.5	<2.5	10
Zinc	50	63	300

Sources: Melbourne samples;[33] suggested tolerance levels by Melsted.[34]

Table VIII-4.—*Accumulation of trace elements in corn plants grown on soil irrigated for 5 years with effluent*[36]

Sample	1	2	3	4	Suggested tolerance level[a]	Toxic level[b]
Barium	13	14	10	15	200	–
Boron	13	16	11	11	150	>75
Cadmium	<5	<5	<5	<5	3	–
Cobalt	<1	<1	<1	<1	5	–
Copper	4.5	4.6	4.5	4.0	150	>20
Chromium	<1	<1	<1	<1	2	–
Lead	<1	<1	<1	<1	10	–
Manganese	16	14	11	15	300	–
Molybdenum	2.1	1.8	1.9	1.7	3	–
Nickel	1.6	1.0	1.0	1.0	3	>50
Silver	0.30	0.26	0.28	0.24	–	–
Vanadium	<1	<1	<1	<1	2	>10
Zinc	33	28	22	16	300	>200

Note: All values expressed in parts per million (ppm).
[a]Source: *Soil-Plant Relationships*, S. W. Melsted.[34]
[b]Source: *Fate and Effects of Trace Elements in Sewage Sludge When Applied to Agricultural Lands*, A. L. Page[37]

INSECT PROPAGATION

Propagation of mosquitoes and flies poses a health hazard as well as a nuisance condition. Mosquitoes are known vectors of several diseases.[27] In the Pennsylvania State study, mosquitoes increased in population mainly because of the wetter environment and the availability of standing puddles for breeding.[7]

At several California industrial land application sites, the major adverse environmental effect has been the propagation of mosquitoes. At Hunt-Wesson in Davis, California, the problem was anticipated, and mosquito fish or gambusia were planted in the runoff collection sump. Where vegetation is grown, ample drying time should be scheduled in the operation to prevent massive mosquito propagation.

Chapter IX

MONITORING

As with any wastewater treatment facility, a comprehensive monitoring program will be required to ensure that proper renovation of wastewater is occurring and that environmental degradation is not occurring. Some monitoring requirements are similar to those required for conventional systems. One example of this is the monitoring of water quality at various stages in the process prior to application. Other monitoring requirements are generally unique to land application systems, and these are the only ones discussed here. They are presented in three categories:

- Renovated water
- Vegetation
- Soils

RENOVATED WATER

The monitoring of renovated water may be required for either groundwater or recovered water or both. Recovered water may include runoff from overland flow or water from recovery wells or underdrains.

Groundwater

Water quality parameters that should be analyzed in the groundwater include:

- Those normally required for drinking water supplies
- Those that may be required for state or local agencies
- Those necessary for system control

Generally, nitrate nitrogen is the parameter that must be most closely observed. To assess the overall impact of the system, changes in groundwater quality can be compared with the quality of background wells. An example of an operational and compliance monitoring schedule for an irrigation system is given in table IX-1, showing the constituents to be monitored and the frequency of sampling.

Table IX-1.—*Example of operational and compliance monitoring schedule for an irrigation system*

Parameter[a]	Applied effluent	Sampling frequency at various points			
		Onsite wells (3 points)	Background well (1 point)	Perimeter wells (5 points)	Adjacent lake (1 point)
BOD	D	–	–	–	Q
COD[b]	M[c]	Q	Q	Q	Q
Chlorine residual	2D	–	–	–	–
Coliform, fecal	M	Q	Q	Q	Q
Coliform, total	D	Q	Q	Q	Q
Flow	C[d]	–	–	–	–
Nitrogen[e]	M[c]	Q	Q	Q	Q
pH	2D[d]	Q[d]	Q[d]	Q[d]	Q[d]
Phosphorus	M[c]	Q	Q	Q	Q
Suspended solids	D	–	–	–	–
Static water level	–	M[d]	M[d]	M[d]	–

Note: D = One sample or measurement per day
Q = One sample or measurement per quarter
M = One sample or measurement per month
2D = Two samples or measurements per day
C = Continuous measurement and recording

[a]If filtered samples of raw wastewater demonstrate the concentration of a particular health-significant parameter (not given above) to be in excess of the permissible limit for drinking water sources, that parameter will be included in this schedule.

[b]May also use TOC to establish a long-term correlation with BOD.

[c]Denotes samples to be 24-hour composites. All others are grab samples.

[d]Field measurement.

[e]Total nitrogen for effluent; nitrate-nitrogen for groundwater.

In addition to changes in quality, changes in groundwater levels should also be monitored. The effect of increased levels should be assessed with respect to changes in the hydrogeologic conditions of the area. Changes in groundwater movement and the appearance of seeps and perched water tables should be noted, and system modifications, such as underdraining or reducing application rates in the area, should be undertaken.

Recovered Water

Monitoring requirements for recovered water will depend on the disposition of that water. If the water is to be discharged, the parameters to be analyzed must include those required by the NPDES permit. If the water is to be reused, analysis of additional parameters may be required by cognizant public health agencies.

Monitoring of the flow rate of recovered water may be important for system control and may also be required as a result of water rights considerations.

VEGETATION

When vegetation is grown as a part of the treatment system, monitoring may be required to optimize growth and yield. Conventional farm management techniques would generally apply; however, in many cases, special factors must be considered because of the normally higher hydraulic loading rates.

For some systems, a more detailed vegetation monitoring program may be required in which the uptake of certain elements is analyzed. Melsted[34] suggests levels for micronutrients in plants as well as methods of sampling. This analysis would generally be required only in cases where potentially toxic constituents are present in the wastewater in abnormally high concentrations.

SOILS

In almost all cases, the application of wastewater to the land will result in some changes in the characteristics of the soil. Consequently, some sort of soil monitoring program will be necessary for most systems, with at least annual sampling recommended. Characteristics that are commonly of interest include:

- Salinity
- Levels of various elements
- pH
- Cation exchange capacity

Salinity

The salinity of the soil, as measured by electrical conductivity, is of extreme concern in many arid portions of the country. High levels of salinity are injurious to most plants in various degrees.[9] Remedial action, such as leaching or underdrainage, may be required.

Levels of Various Elements

One area of major concern in many cases is the sodium adsorption ratio. High values may adversely affect the permeability of some soils, as discussed previously.[8,9] Levels of nitrogen, phosphorus, potassium, magnesium, and calcium are also important.

Levels of boron and a number of metals, such as cadmium, may also be of concern in many cases because of their effects on crop growth and crop marketability, respectively. Many such elements are micronutrients that are required for the proper growth of plants. At high levels, however, they may be toxic to plants or animals in the food chain, as well as to humans.

pH

The optimum soil pH range for retention of many wastewater constitutents is the neutral range (pH 6-7). Because wastewater usually has a neutral pH, fluctuations in soil pH are uncommon but do sometimes occur. Should decreases in soil pH occur, they can be corrected by the addition of lime.

Cation Exchange Capacity

The cation exchange capacity is an important parameter because of its role in the chemical renovation of the water. The cation exchange sites may be occupied by ammonium, calcium, magnesium, potassium, sodium, and hydrogen ions. Competition for the available sites depends on the relative concentrations of these ions in the percolating water and in the soil, and this competition is reflected in the quality of the renovated water. The change in percent of available sites occupied by each cation is the important trend to monitor. If one cation, such as sodium, builds up excessively, remedial measures, such as adding amendments, should be considered.

REFERENCES

[1] R. D. Johnson, "Land Treatment of Wastewater," *The Military Engineer,* 65, No. 428, 1973, pp. 375-378.

[2] C. E. Pound and R. W. Crites, *Wastewater Treatment and Reuse by Land Application,* Volumes I and II, Environmental Protection Agency, Office of Research and Development, EPA-660/2-73-006 a, b, August 1973.

[3] R. E. Thomas, et al., *Feasibility of Overland Flow for Treatment of Raw Domestic Wastewater,* Environmental Protection Agency, Office of Research and Development, EPA-660/2-74-087, July 1974.

[4] C. E. Pound and R. W. Crites, "Characteristics of Municipal Effluents," *Proceedings of the Joint Conference on Recycling Municipal Sludges and Effluents on Land,* Champaign, University of Illinois, July 1973, pp. 49-62.

[5] W. A. Cowlishaw, "Update on Muskegon County, Michigan, Land Treatment System," ASCE Annual and National Environmental Engineering Convention, Kansas City, Missouri, October 1974.

[6] T. G. Bahr, et al., *Wastewater Use in the Production of Food and Fiber–Proceedings,* The Michigan State University Water Quality Management Program, EPA-660/2-74-041, June 1974.

[7] L. T. Kardos, et al., *Renovation of Secondary Effluent for Reuse as a Water Resource,* Environmental Protection Agency, Office of Research and Development, EPA-660/2-74-016, February 1974.

[8] "Diagnosis and Improvement of Saline and Alkali Soils," *Agriculture Handbook No. 60,* U.S. Department of Agriculture, U.S. Salinity Laboratory, 1954.

[9] *Evaluation of Land Application Systems,* Environmental Protection Agency, Office of Water Program Operations, EPA-430/9-75-001, March 1975.

[10] R. S. Ayers, "Water Quality Criteria for Agriculture," University of California-Committee of Consultants, California Water Resources Control Board, April 1973.

[11] S. C. Reed, et al., "Pretreatment Requirements for Land Application of Wastewaters," presented at the Second ASCE National Conference on Environmental Research, Development, and Design, University of Florida, July 20-23, 1975.

[12] C. H. Pair (ed.), *Sprinkler Irrigation,* 3rd edition and supplement, Washington, D.C., Sprinkler Irrigation Association, 1969, 1973.

[13]"Sprinkler Irrigation," *SCS National Engineering Handbook*, Section 15, Chapter 11, U.S. Department of Agriculture, Soil Conservation Service, July 1968.

[14]"A Guide to Planning and Designing Effluent Irrigation Disposal Systems in Missouri," University of Missouri Extension Division, March 1973.

[15]K. W. Flach, "Land Resources," *Proceedings of the Joint Conference on Recycling Municipal Sludges and Effluents on Land*, Champaign, University of Illinois, July 1973, pp. 113-120.

[16]D. M. Whiting, *Use of Climatic Data in Design of Soil Treatment Systems*, Environmental Protection Agency, Office of Research and Development, EPA-660/2-75-018, July 1975.

[17]W. Viessman, Jr., T. E. Harbaugh, and J. W. Knapp, *Introduction to Hydrology*, Intext Educational Publishers: New York, 1972.

[18]V. J. Kilmer, et al., "Nutrient Losses from Fertilized Grassed Watersheds in Western North Carolina," *Jour. of Environmental Quality*, 3, No. 3, 1974, pp. 214-219.

[19]S. D. Klausner, et al., "Surface Runoff Losses of Soluble Nitrogen and Phosphorus Under Two Systems of Soil Management," *Jour. of Environmental Quality*, 3, No. 1, 1974, pp. 42-46.

[20]K. H. Nicholls and H. R. MacCrimmon, "Nutrients in Subsurface and Runoff Waters of the Holland Marsh, Ontario," *Jour of Environmental Quality*, 3, No. 1, 1974, pp. 31-35.

[21]D. R. Timmons, R. E. Burwell, and R. F. Holt, "Nitrogen and Phosphorus Losses in Surface Runoff from Agricultural Land as Influenced by Placement of Broadcast Fertilizer," *Water Resources Research*, Vol. 9, No. 3, June 1973, p. 658.

[22]C. W. Thornthwaite Associates, "An Evaluation of Cannery Waste Disposal by Overland Flow Spray Irrigation," *Publications in Climatology*, 22, No. 2, September 1969.

[23]C. A. Sorber, et al., "Bacterial Aerosols Created by Spray Irrigation of Wastewater," 1975 Sprinkler Irrigation Association Technical Conference, Atlanta, Georgia, February 1975..

[24]C. P. C. Poon, "Viability of Long Storaged Airborne Bacterial Aerosols," *ASCE San. Engr. Div., 94*, No. SA 6, 1968, pp. 1136-1146.

[25]C. A. Sorber and K. J. Guter, "Health and Hygiene Aspects of Spray Irrigation," *American Journal of Public Health*, 65, No. 1, 1975, pp. 47-52.

[26]E. Sepp, "The Use of Sewage for Irrigation–A Literature Review," Bureau of Sanitary Engineering, California State Department of Public Health, Berkeley, 1971.

[27]C. A. Sorber, "Protection of Public Health," *Proceedings of the Conference on Land Disposal of Municipal Effluents and Sludges*, New Brunswick, Rutgers University, March 12-13, 1973, pp. 201-209.

[28]S. G. Dunlop, "Survival of Pathogens and Related Disease Hazards," *Proceedings of the Symposium on Municipal Sewage Effluent for Irrigation*, Louisiana Polytechnic Institution, July 30, 1968.

[29]M. A. Benarde, "Land Disposal and Sewage Effluent: Appraisal of Health Effects of Pathogenic Organisms," *Jour. AWWA*, 65, No. 6, 1973, pp. 432-440.

[30]P. J. Napolitano and D. R. Rowe, "Microbial Content of Air Near Sewage Treatment Plants," *Water and Sewage Works*, December 1966, pp. 480-488.

[31]Fritz R. Dixon and Leland J. McCable, "Health Aspects of Wastewater Treatment," *JWPCF*, Vol. 36, No. 8, August 1964, pp. 984-989.

[32]"Proposed Environmental Protection Agency Regulations on Interim Primary Drinking Water Standards," Environmental Protection Agency, 40 CFR 141, March 10, 1975.

[33]R. D. Johnson, et al., "Selected Chemical Characteristics of Soils, Forages, and Drainage Water from the Sewage Farm Serving Melbourne, Australia," Prepared for the Department of the Army, Corps of Engineers, January 1974.

[34]S. W. Melsted, "Soil-Plant Relationships (Some Practical Considerations in Waste Management)," *Proceedings of the Joint Conference on Recycling Municipal Sludges and Effluents on Land*, Champaign, University of Illinois, July 1973, pp. 121-128.

[35]E. J. Underwood, *Trace Elements in Human and Animal Nutrition*, Academic Press: New York, 1971.

[36]L. M. Harwood and E. W. Holtz, "Progress Report of Reclamation of Waste Water Forage Crop Trials," Sonoma County, Agricultural Extension, University of California, 1974.

[37]A. L. Page, *Fate and Effects of Trace Elements in Sewage Sludge When Applied to Agricultural Lands*, Environmental Protection Agency, Office of Research and Development, EPA-670/2-74-005, January 1974.